CLICPIX2+PLANAR:

Test-beam analysis improvements

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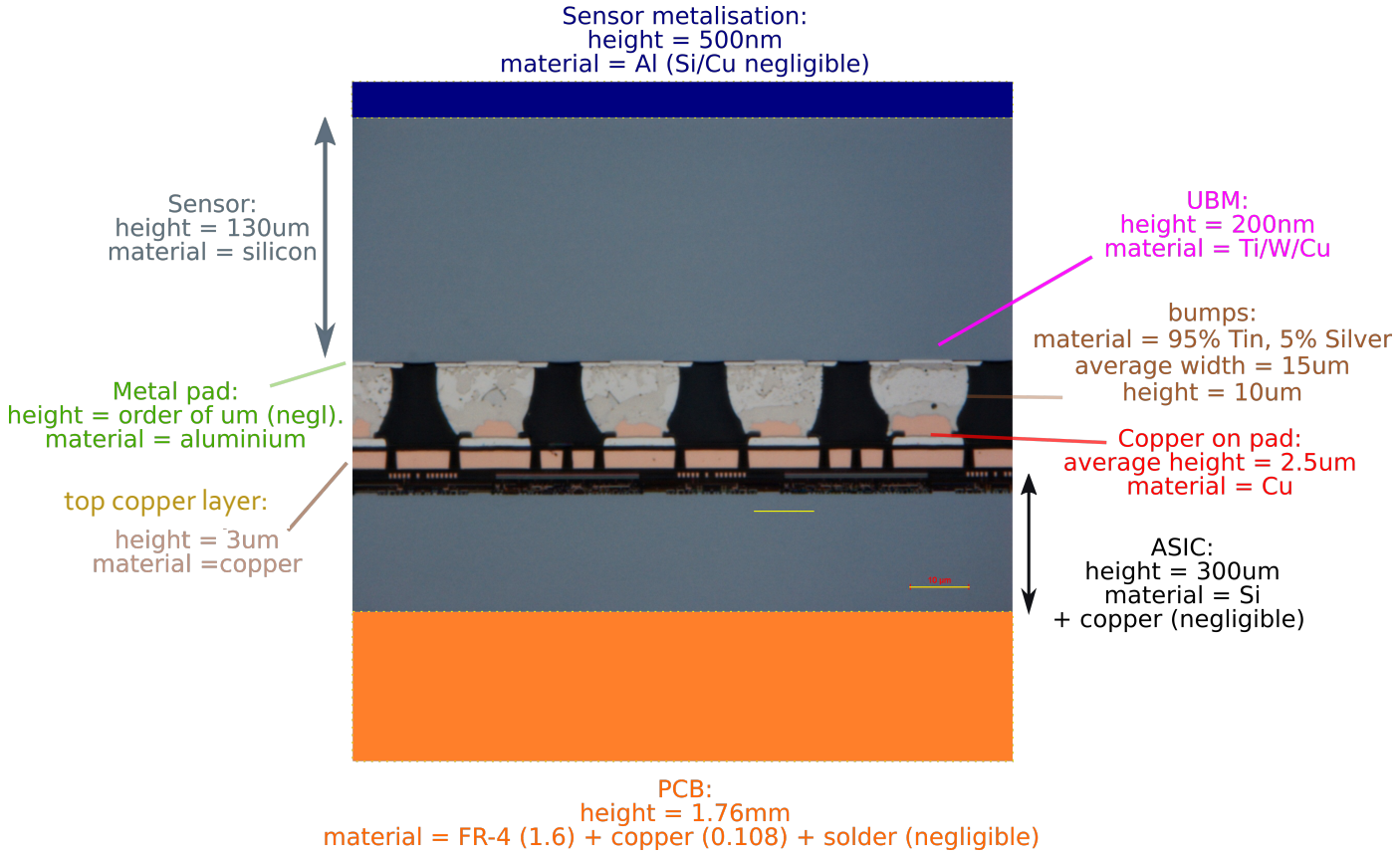
1) MATERIAL BUDGET

CLICpix2 layers

- Material budget for each telescope plane is needed for General Broken Lines (GBL) track model implementation in Corryvreckan
- This track model can correctly take into account scattering layers in the telescope.
- For CLICpix2, need thicknesses and materials used in each layer of the device to calculate overall X/X0

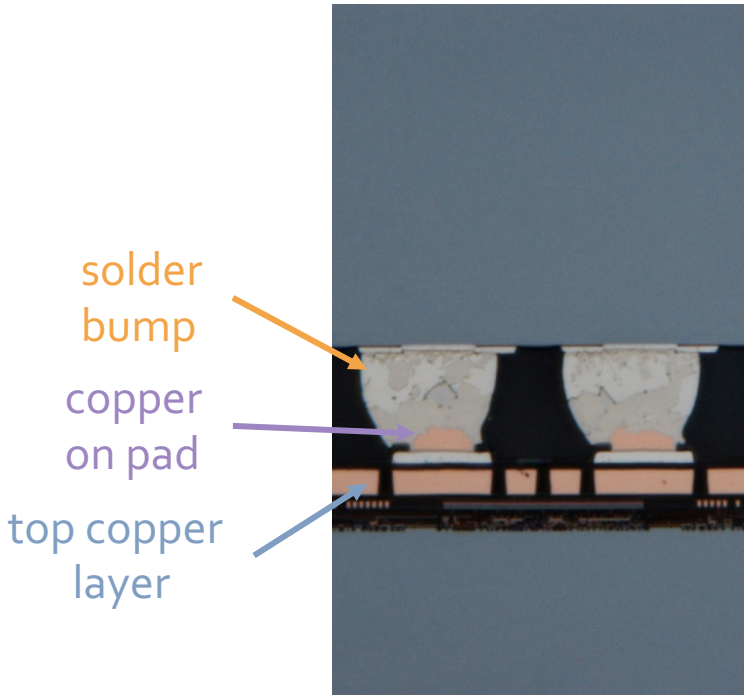
Material budget calculation

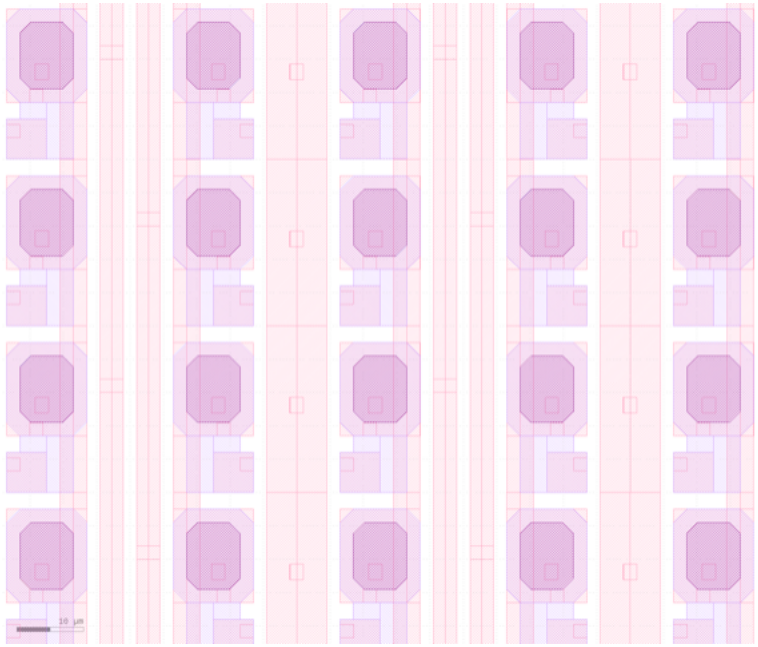
- Image, right: composite image of CLICpix2+planar assembly cross-section from IZM and box representations of other layers
- Most information already known to us, any unknowns were estimated.
- Bump shape and size estimated using scale of cross-sectional image
- Size and shape of top copper layer estimated from design schematic



Effective thickness

- For the three layers that are not flat and uniform, an effective thickness was calculated
- Calculated for the solder bumps, copper on the pixel pad, and top copper layer.
- For example, the volume of each solder bump was calculated from the size estimates and this volume of material modelled as a flat layer with an effective thickness.





Layer	*material*	*Xo (mm)*	*Thickness (um)*	*X/Xo (%)*
Sensor metalisation	Al	88.97	0.5	0.000562
	Si	-	negligible %	-
	Cu	-	negligible %	-
Sensor	Si	93.7	130	0.138741
Metal pad	Al	-	negligible thickness	-
UBM	Ti	35.6	0.2	0.000562
	W	-	negligible %	-
	Cu	-	negligible %	-
Solder Bump	Tin (95%)	12.06	361	0.002993
	Silver (5%)	8.54	19	0.000222
Copper on pad	Cu	-	negligible thickness	-
Top copper layer	Cu	14.36	1.985	0.013823
ASIC	Si	93.7	300	0.320171
	Cu	-	negligible %	-
PCB	FR4 (60% glass fiber)	97.66	960	0.983002
	FR4 (40% epoxy resin)	349.89	640	0.182915
	Cu	14.36	108	0.752089
	Solder	-	negligible thickness	-
			Total	2.395080

Layer X/Xo calculation = 2.4%

2) GBL IN TEST-BEAM ANALYSIS

Implementing GBL into analysis

- GBL: General Broken Lines
- GBL particle track model takes into account scattering by material at each plane of the telescope, important to model for lower energy test-beam environments
- Updates to my Corryvreckan analysis since last talk:
    - GBL track model
    - Each plane has correct material budget
    - TPx3 included in reconstruction and used for the track timestamp
    - Implemented relative timing and spatial cuts (update from v1.0)
    - Additional masking of noisy pixels at thresholds lower than the operational value
    - Using updated threshold calibration for threshold values in electrons

Configuration

- Changes to configuration files:

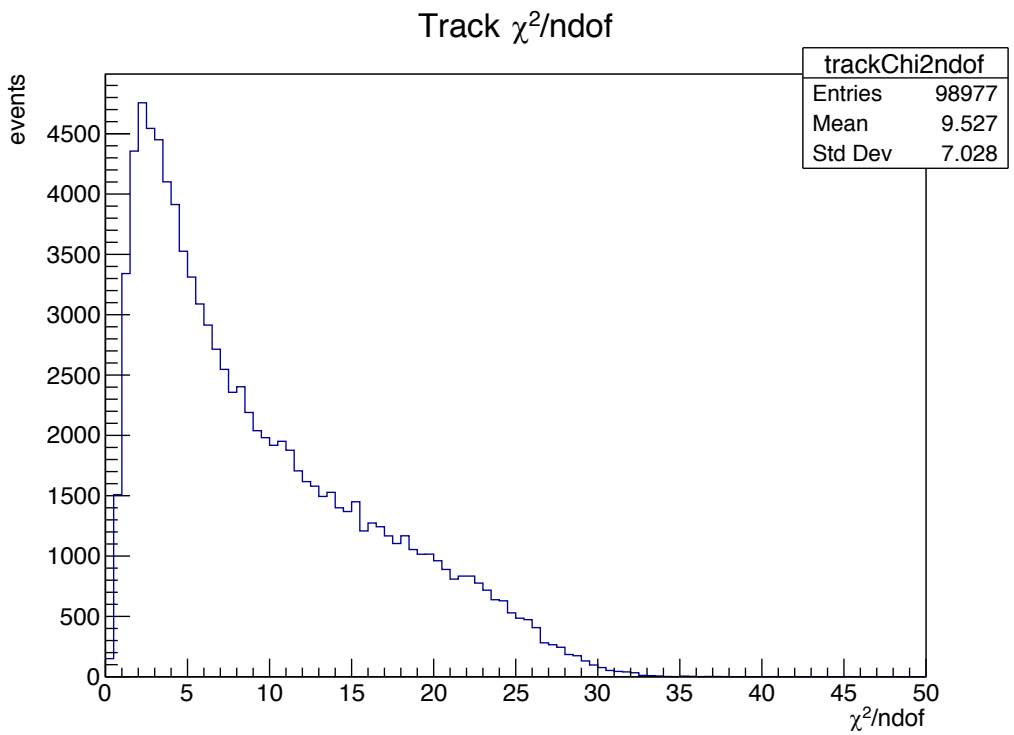
Main.conf (before)
…
[Tracking4D]
track_model="straightline"

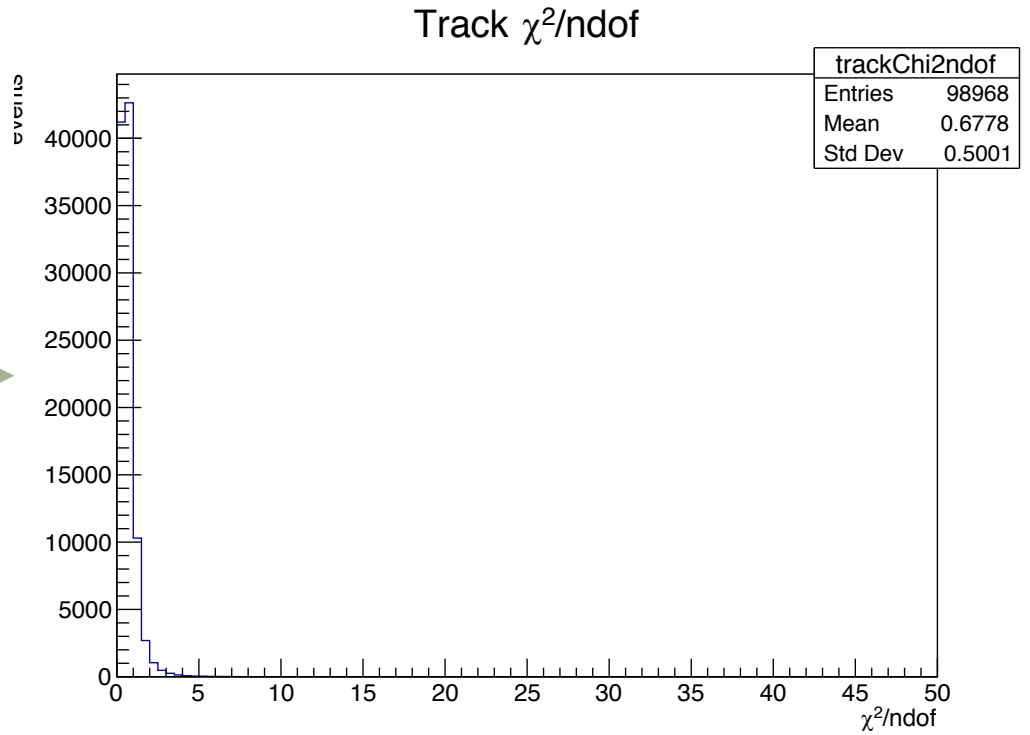
spatial_cut_abs=65um,65um
min_hits_on_track=6
time_cut_rel=2.0
require_detectors="Timepix3_0"
timestamp_from="Timepix3_0"
…

Main.conf (now)
…
[Tracking4D]
track_model="gbl"
momentum=5.4GeV
spatial_cut_abs=65um,65um
min_hits_on_track=6
time_cut_rel=2.0
require_detectors="Timepix3_0"
timestamp_from="Timepix3_0"
…

Difference for a single run

- Run 1013: DESY July test-beam, CLICpix2+planar assembly 20, -25V applied bias, threshold of ~664 electrons, same amount of data reconstructed





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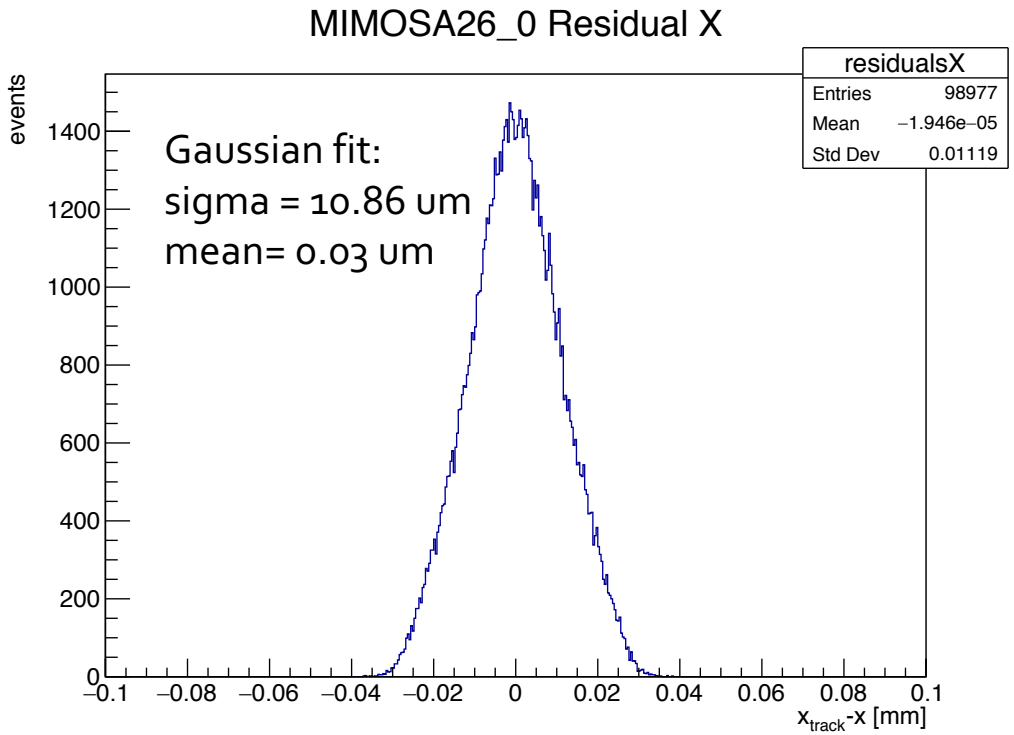

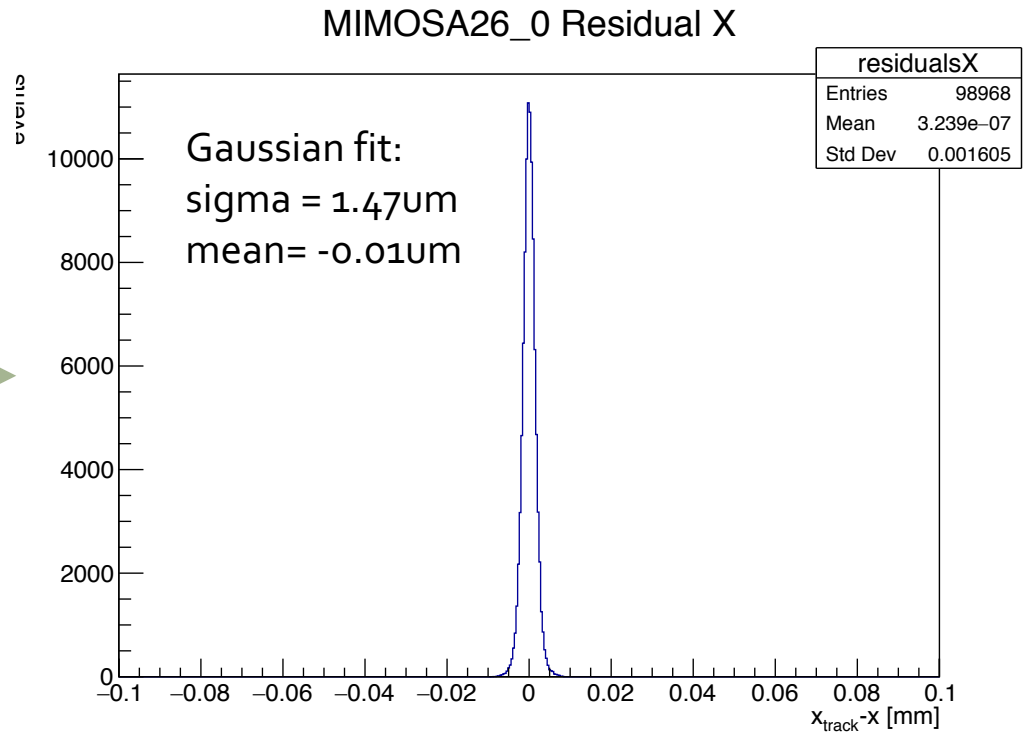

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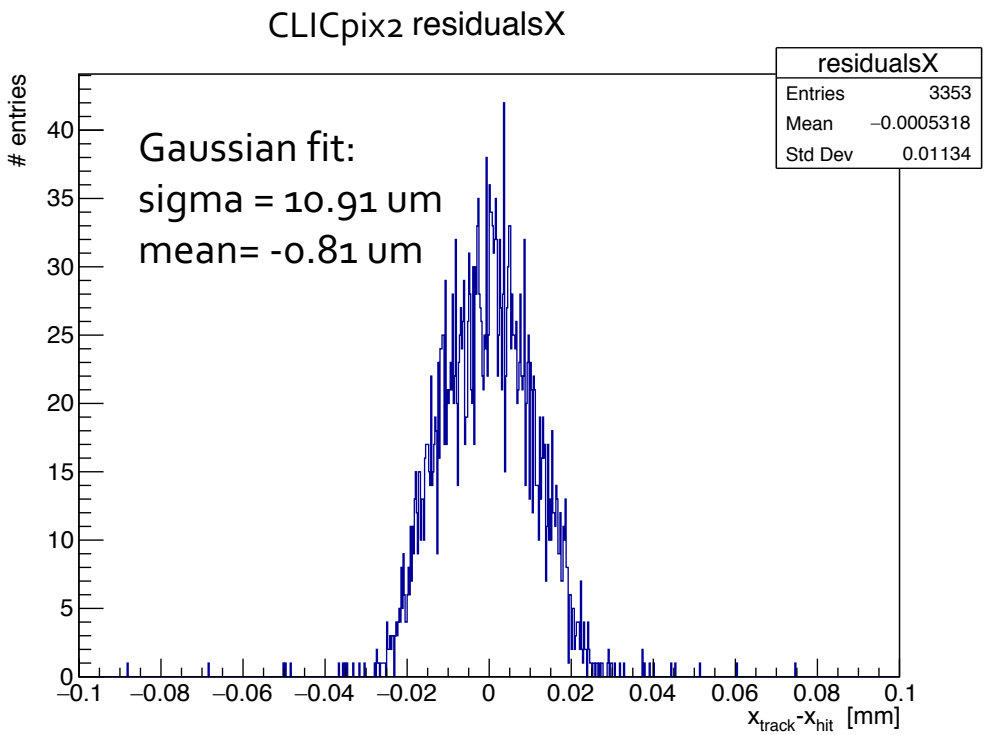

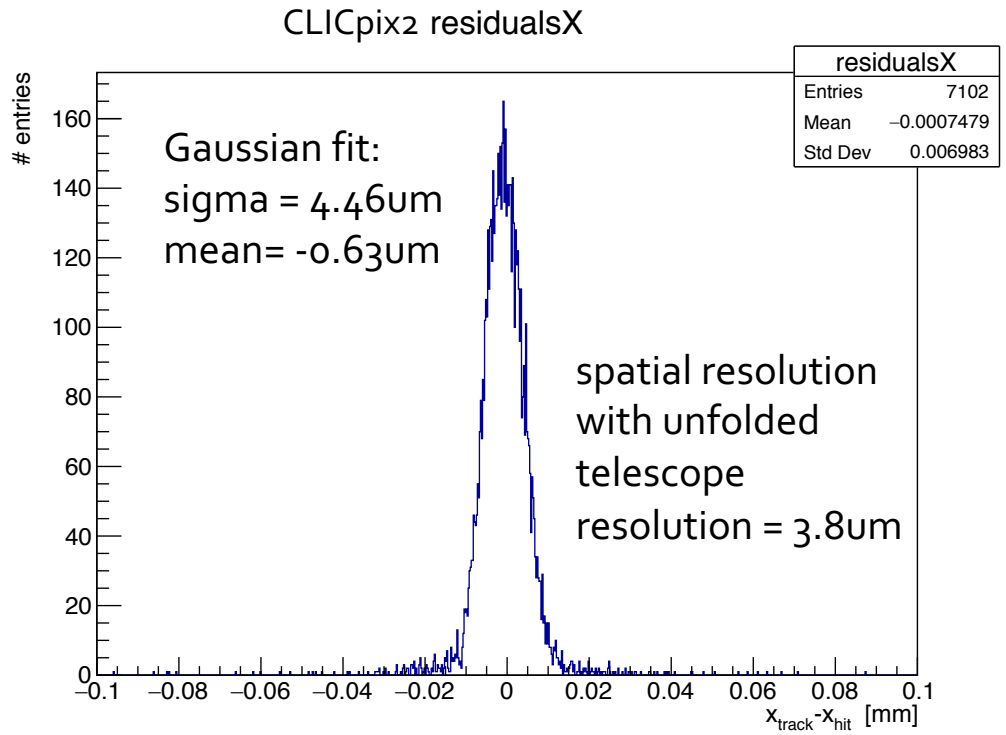

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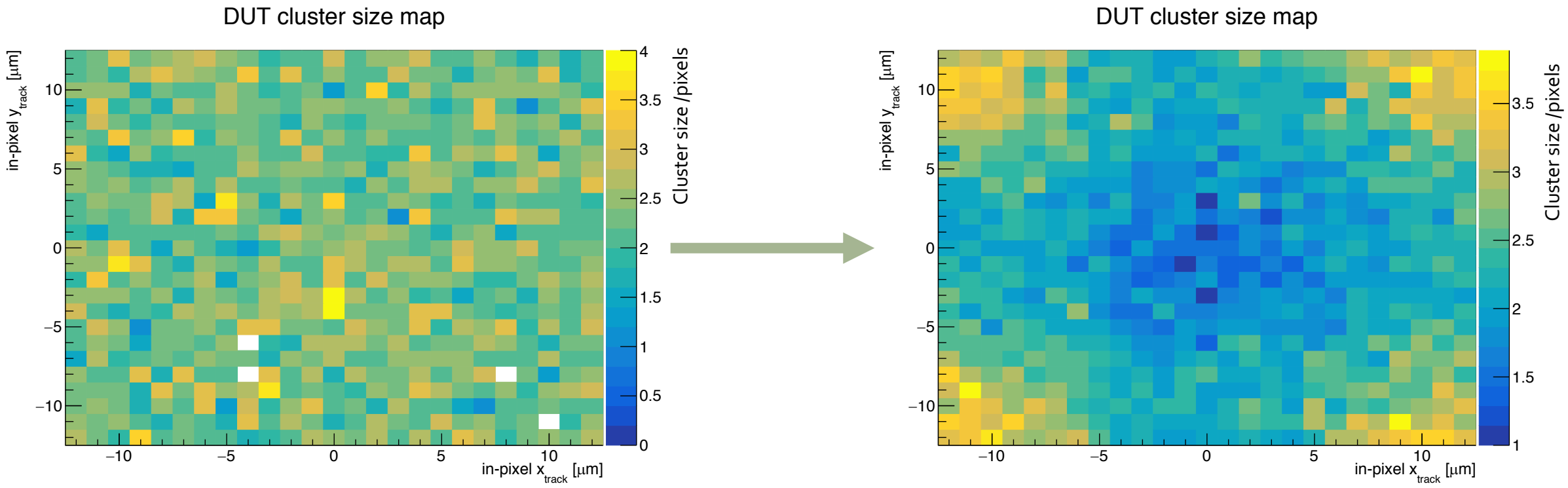


Difference for a single run

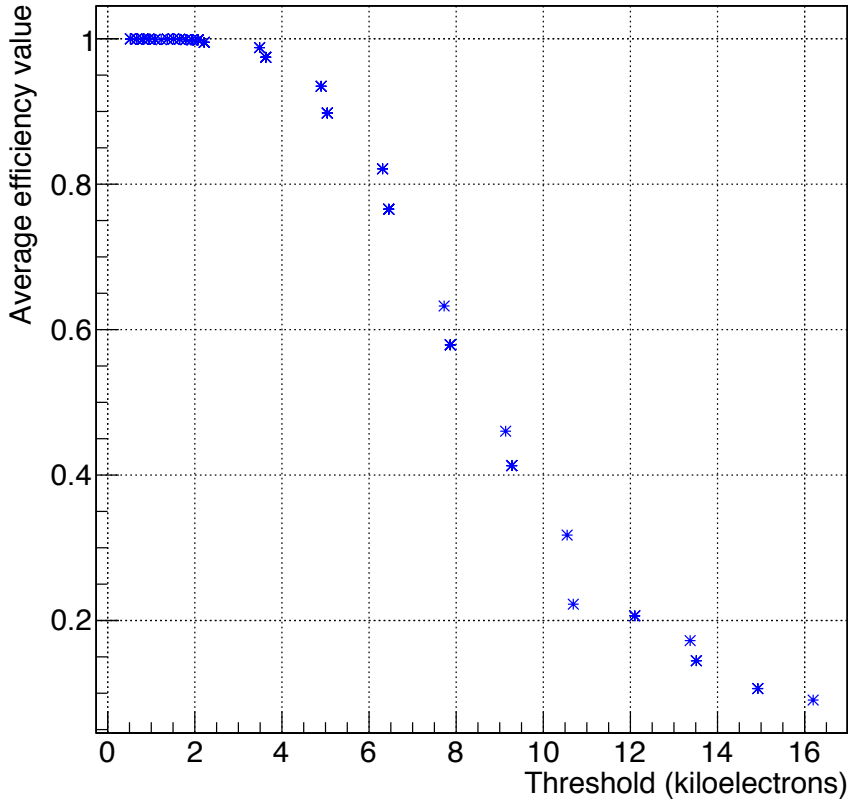
- Run 1013: DESY July test-beam, CLICpix2+planar assembly 20, -25V applied bias, threshold of ~664 electrons

Efficiency = 99.4575%

Efficiency = 99.9713%

Updated efficiency values for threshold scan

- DESY July 2019 TB data, assembly 20, -25V bias
- scan of threshold from ~522 electrons to ~16.2k electrons
- Summary: using GBL track model in DESY test-beam analysis improves efficiencies at operational threshold to 99.97% and positional resolution to 4.46 um (3.8 um unbiased)



3) THRESHOLD CALIBRATION

Updated threshold calibration

- Threshold calibration using X-rays, two target materials used
- Updated analysis using only single pixel clusters
- See previous presentation for details of data taking method (4/10/2019)

Updated threshold calibration: assembly 20

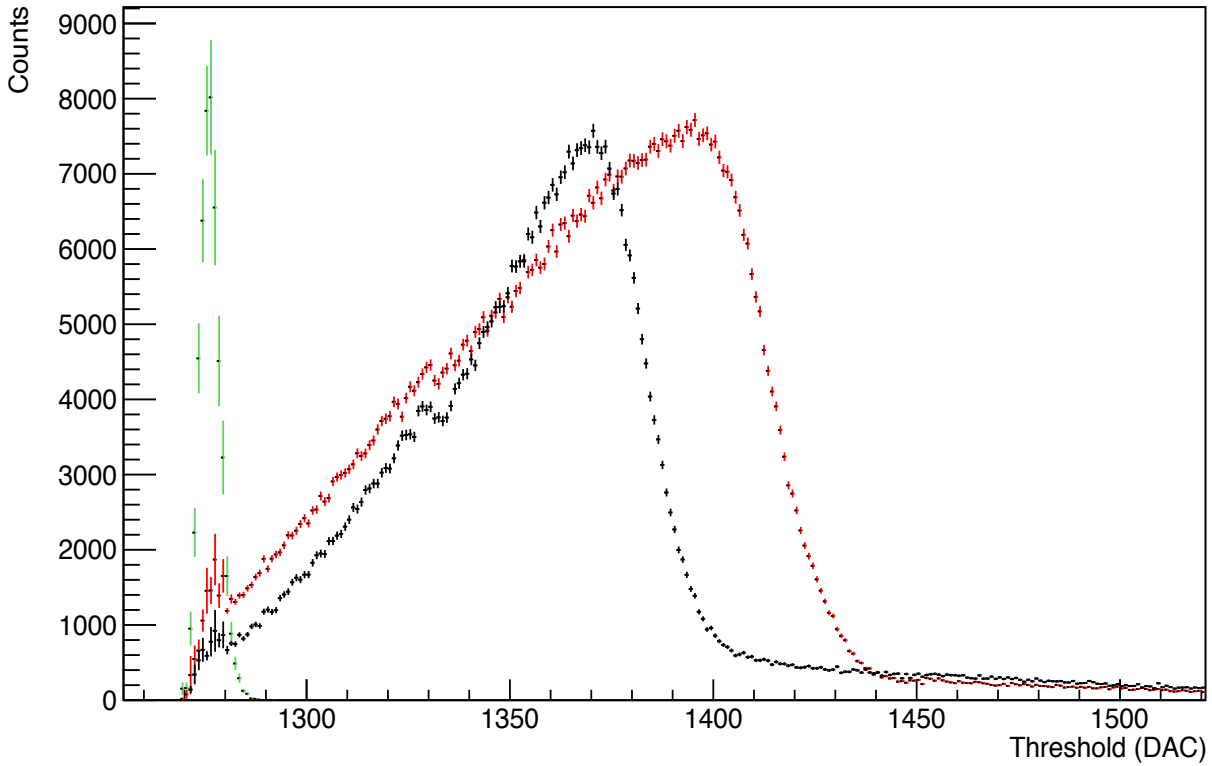
- Three curves are seen:

  green = no beam

  red = copper target

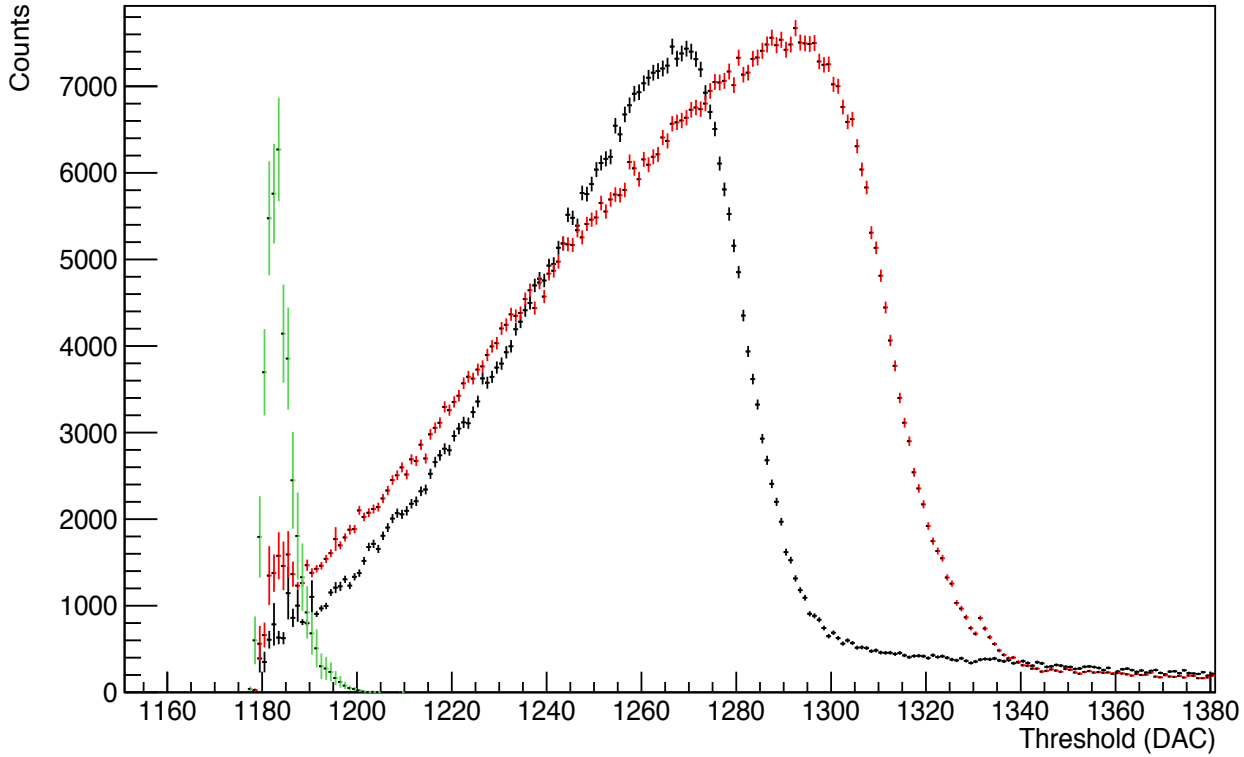
  black = iron target

- Steady increase in counts with higher thresholds -> one pixel clusters are more likely to occur at higher thresholds.
- Maximum of the distribution = energy expected from the target material (6.4keV for iron and 8.04keV for copper).
- Small 'bump' in the assembly 20 curves for both targets at ~1330 THL dac



Updated threshold calibration: assembly 16

- Three curves are seen:
  - green = no beam
  - red = copper target
  - black = iron target
- Similar distribution as for assembly 20
- Small 'bump' in the assembly 16 curves for copper target, again at ~1330 THL DAC



Updated threshold calibration

- Threshold calibration using X-rays, two target materials used
- Updated analysis using only single pixel clusters

- Peak of each target distribution found using a Gaussian fit over high threshold range of the histogram
- Threshold calibrated using a linear fit on three points: copper, iron, baseline
- Assembly 20 : 14.12 electrons/THL DAC (previously calculated value 13.75)
- Assembly 16 : 14.86 electrons/THL DAC

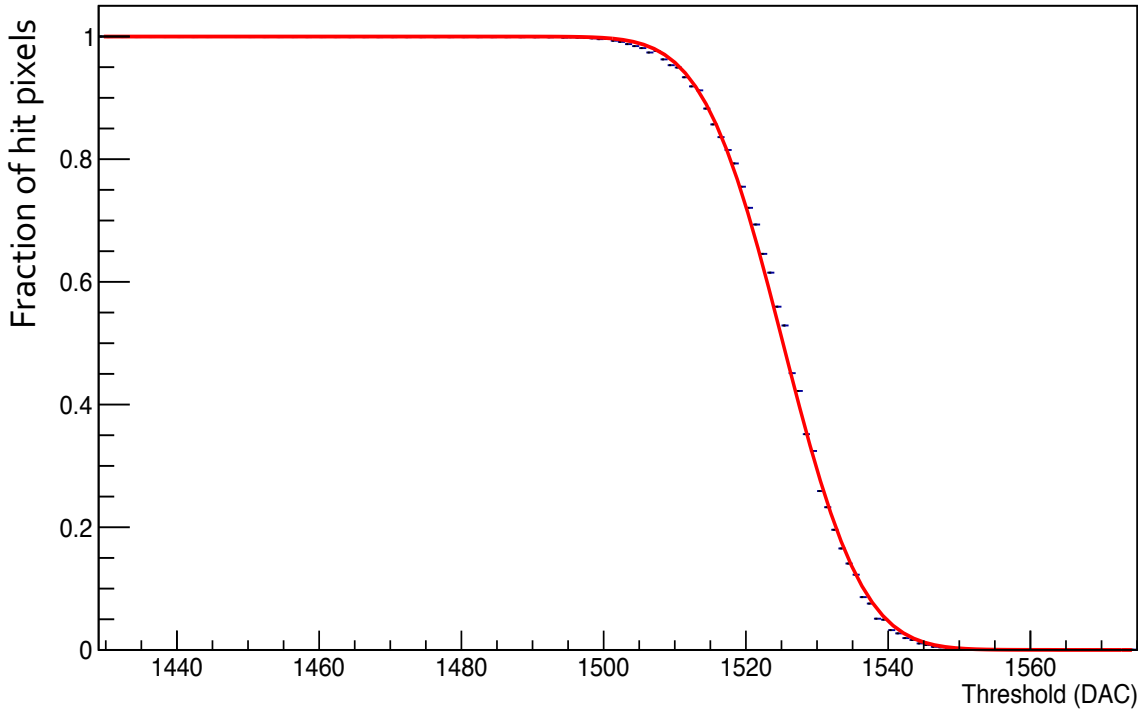
4) TOT CALIBRATION

ToT calibration

- Calibrating ToT response of assembly 20 for application to the test-beam data
- Data was taken with X-ray machine for different clock divider settings and targets -> difficult to analyse due to low granularity of ToT measurement (30bit)
- New method utilises the threshold calibration, as this has much finer binning
- Method requires two sets of data:
  - 1) threshold scan with a fixed test-pulse magnitude to relate pulse height to electrons using existing threshold calibration
  - 2) scan of test-pulse magnitude at a fixed threshold to get a curve for each pixel of ToT vs. pulse height
- Combination of data sets gives calibration curve for each pixel as required

1) Threshold scan

- Scan threshold over wide range for test pulse height of 81mV
- Fit TProfile of hits vs. threshold with an scurve and obtain mean value
- Mean threshold of fit = 1525 THL



1) Threshold scan

- Scan threshold over wide range for test pulse height of 81mV
- Fit TProfile of hits vs. threshold with an scurve and obtain mean value
- Mean threshold of fit = 1525 THL
- Calculated capacitance (capacitor used for generating test pulse):

$$capacitance = \frac{number\ of\ electrons * charge\ of\ an\ electron}{voltage} = \frac{(1525-1243)*14.12*1.602*10^{-19}}{0.081} = 7.88fF$$

- Note: expected capacitance value is 10fF with a 20% error, additional errors may arise from temperature fluctuation effects on the two DAC used for test pulse generation

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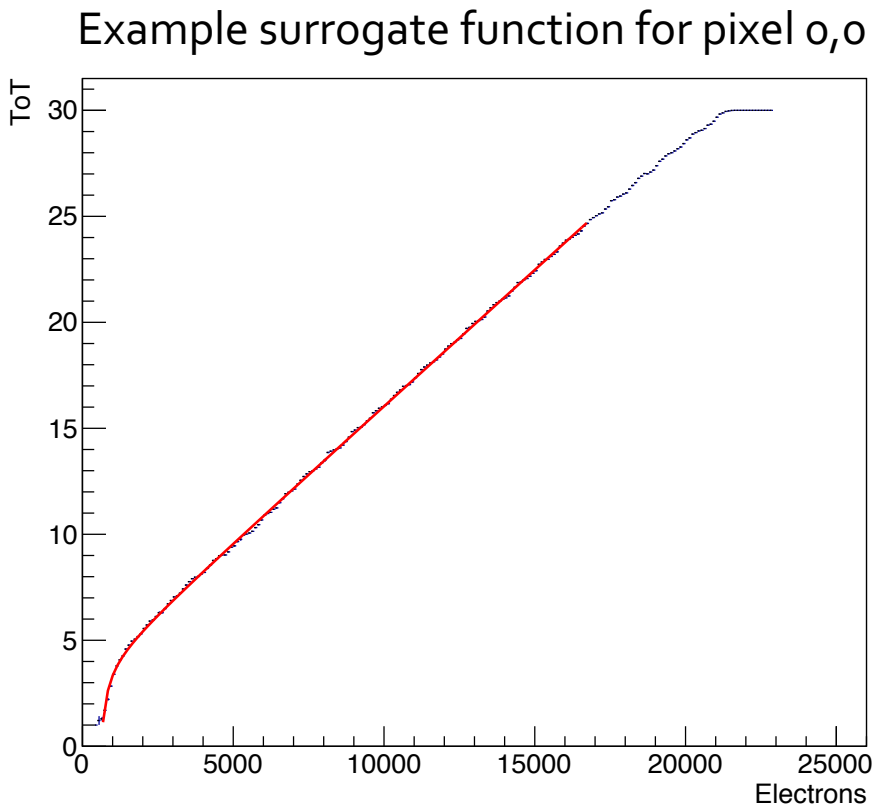
- Calculated mV to electrons conversion factor:

$$conversion\ factor = \frac{C * V}{electron\ charge} = \frac{7.88 * 10^{-15} * 10^{-3}}{1.602 * 10^{-19}} = 49.19\ electrons/mV$$

2) Test pulse height scan

- Scan test pulse height from 0V to ~465mV (0 to 22.9 kelectrons)
- Obtain ToT vs test pulse magnitude (mV) distribution per pixel
- Convert mV to electrons using conversion factor of 49.19 electrons/mV
- Fit each distribution with a surrogate function over appropriate range:

$$y = ax + b \; - \frac{c}{x - t}$$



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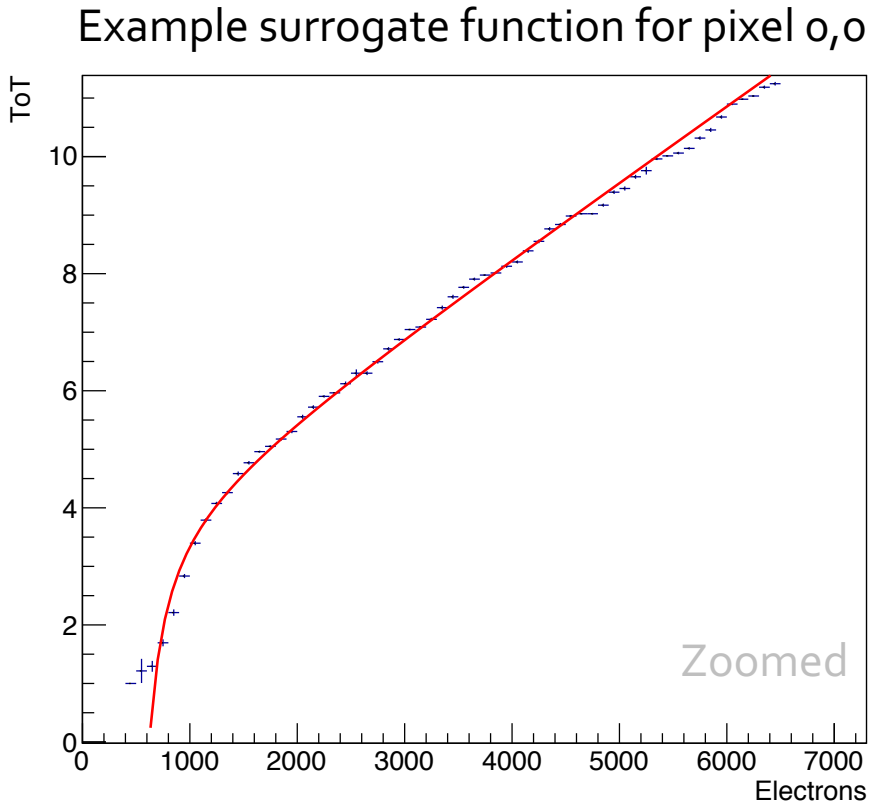


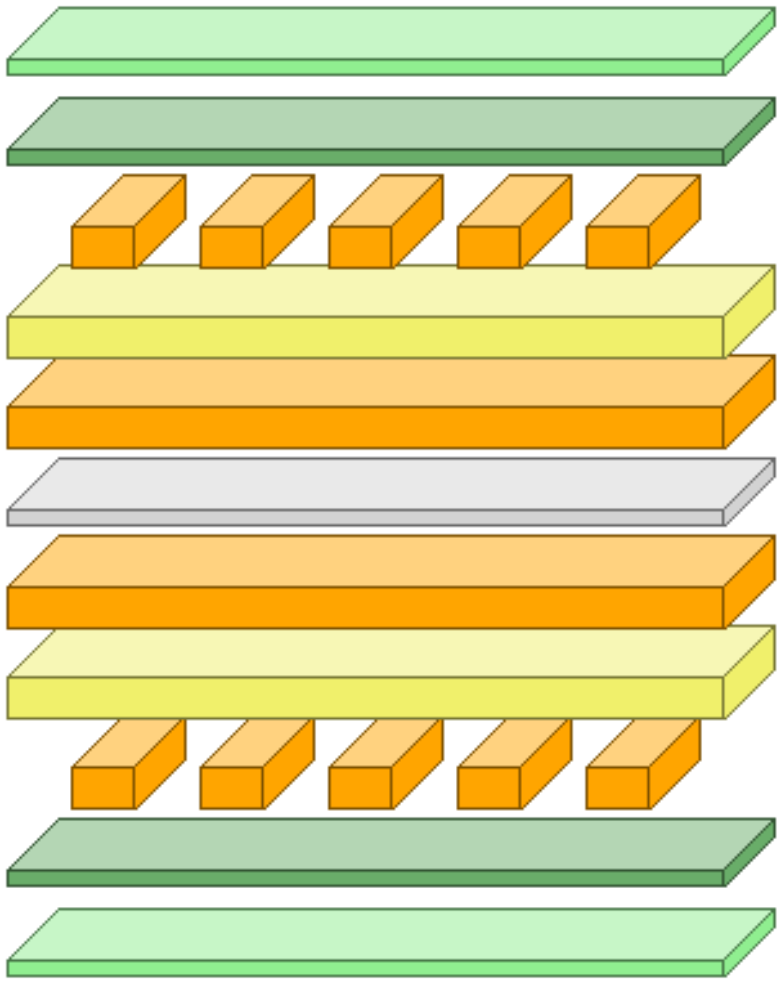
Summary

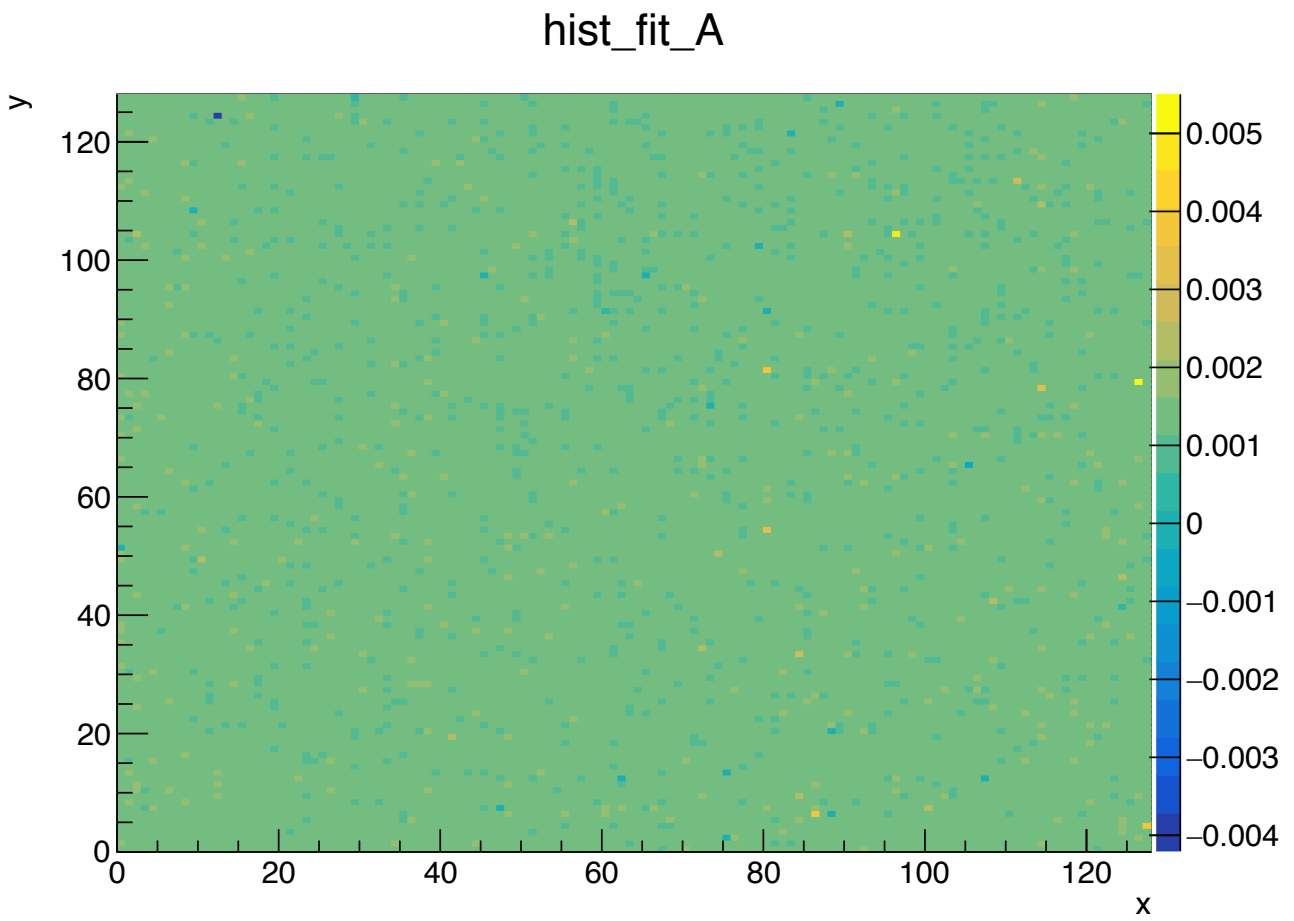
- Material budget of CLICpix2+planar assemblies calculated to be 2.4%.
- Test-beam reconstruction of DESY data vastly improved by using GBL track model.
- CLICpix2 efficiencies of 99.97% at operational threshold and unbiased positional resolution of ~3.8 um.
- Threshold calibration method improved, updated values of 14.12 and 14.86 electrons/THL DAC for assemblies 20 and 16 respectively.
- Test pulse capacitance for assembly 20 calculated to be 7.88fF and conversion factor of 49.19 electrons/mV was calculated.
- ToT calibration performed for assembly 20 using threshold calibration results, implementation to test-beam data is ongoing.

BACKUP

Board Layer Stack

Top Overlay	0.000mm
Top Solder	0.010mm
Top Layer	0.036mm
Dielectric1	0.200mm
GND	0.036mm
Dielectric3	1.200mm
SUPPLY	0.036mm
Dielectric2	0.200mm
Bottom Layer	0.036mm
Bottom Solder	0.010mm
Bottom Overlay	0.000mm

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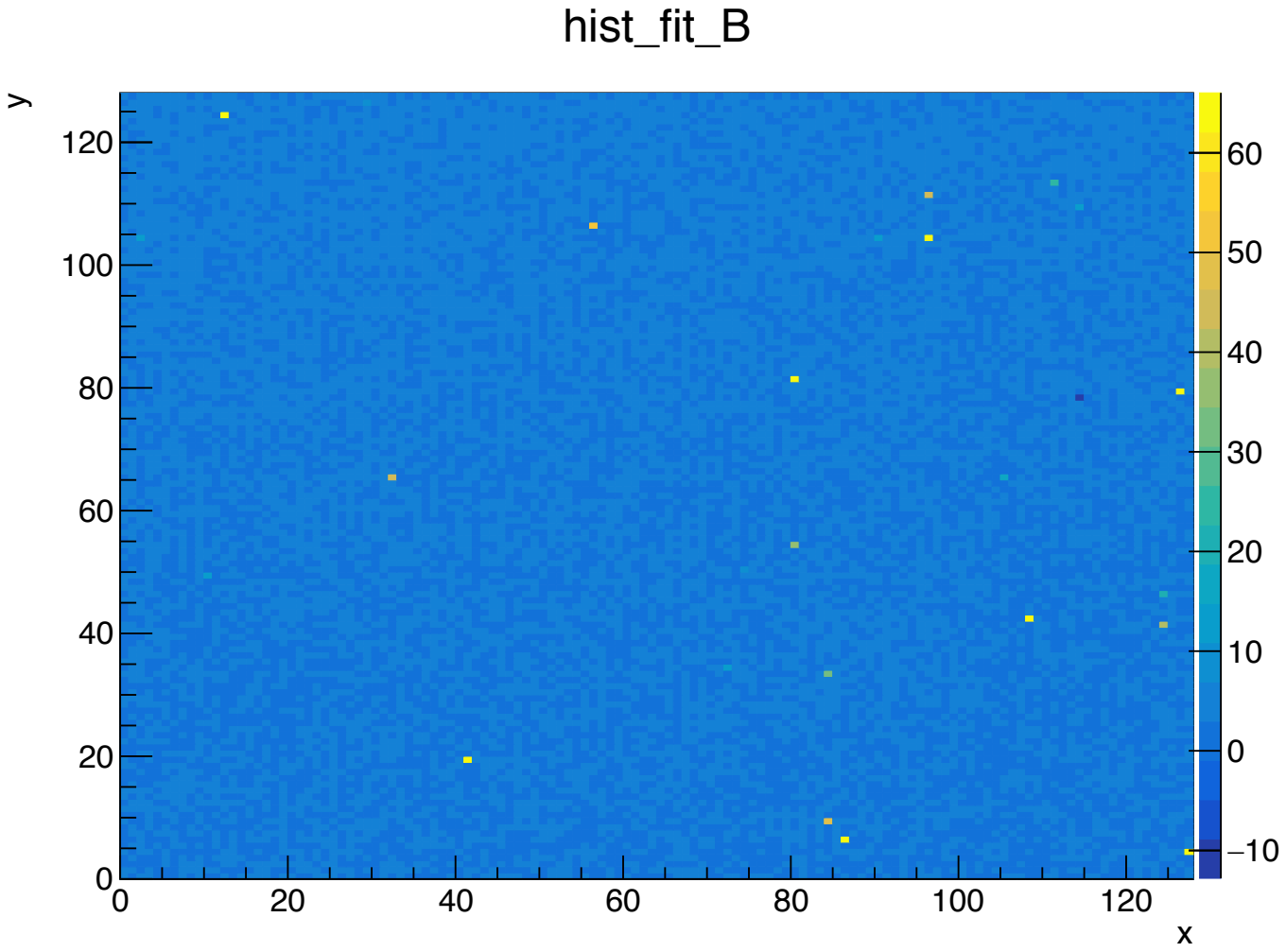
y
120
100
80
60
40
20
0
0
20
40
60
80
100
120
x
0.005
0.004
0.003
0.002
0.001
0
−0.001
−0.002
−0.003
−0.004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y
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100
80
60
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0
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40
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80
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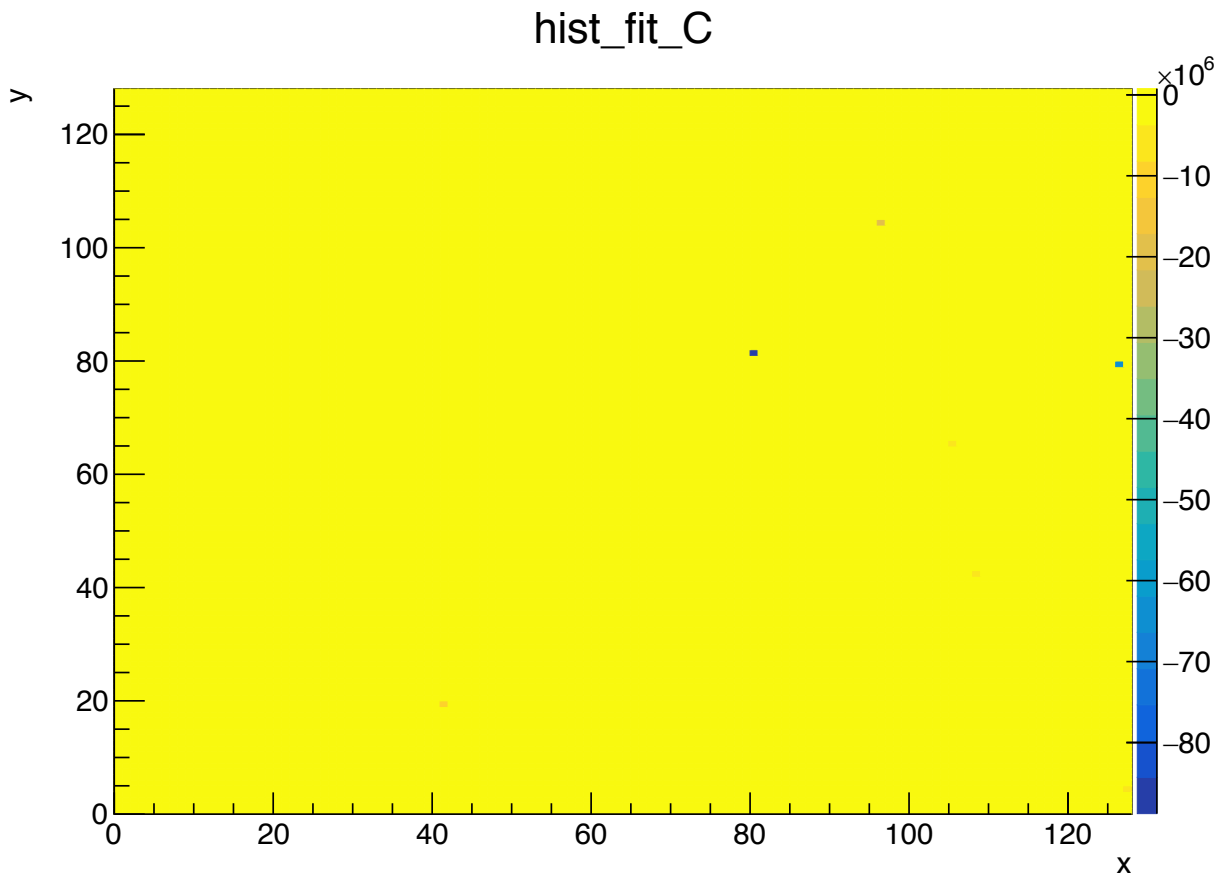
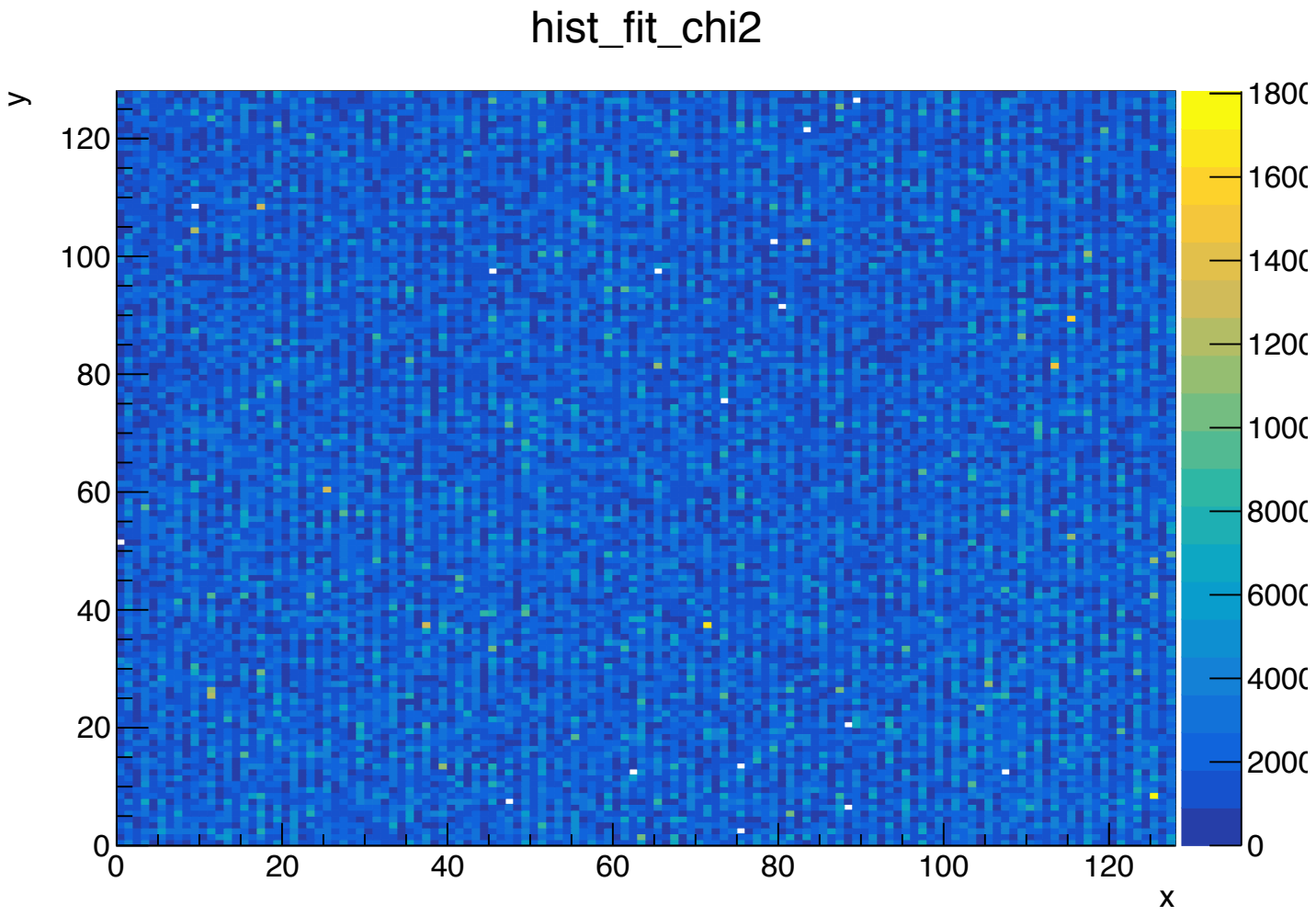
120
x
60
50
40
30
20
10
0
−10


hist_fit_C
y
x
0
20
40
60
80
100
120
×10^6
0
−10
−20
−30
−40
−50
−60
−70
−80


hist_fit_chi2
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100
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60
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x
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1600
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1200
1000
800
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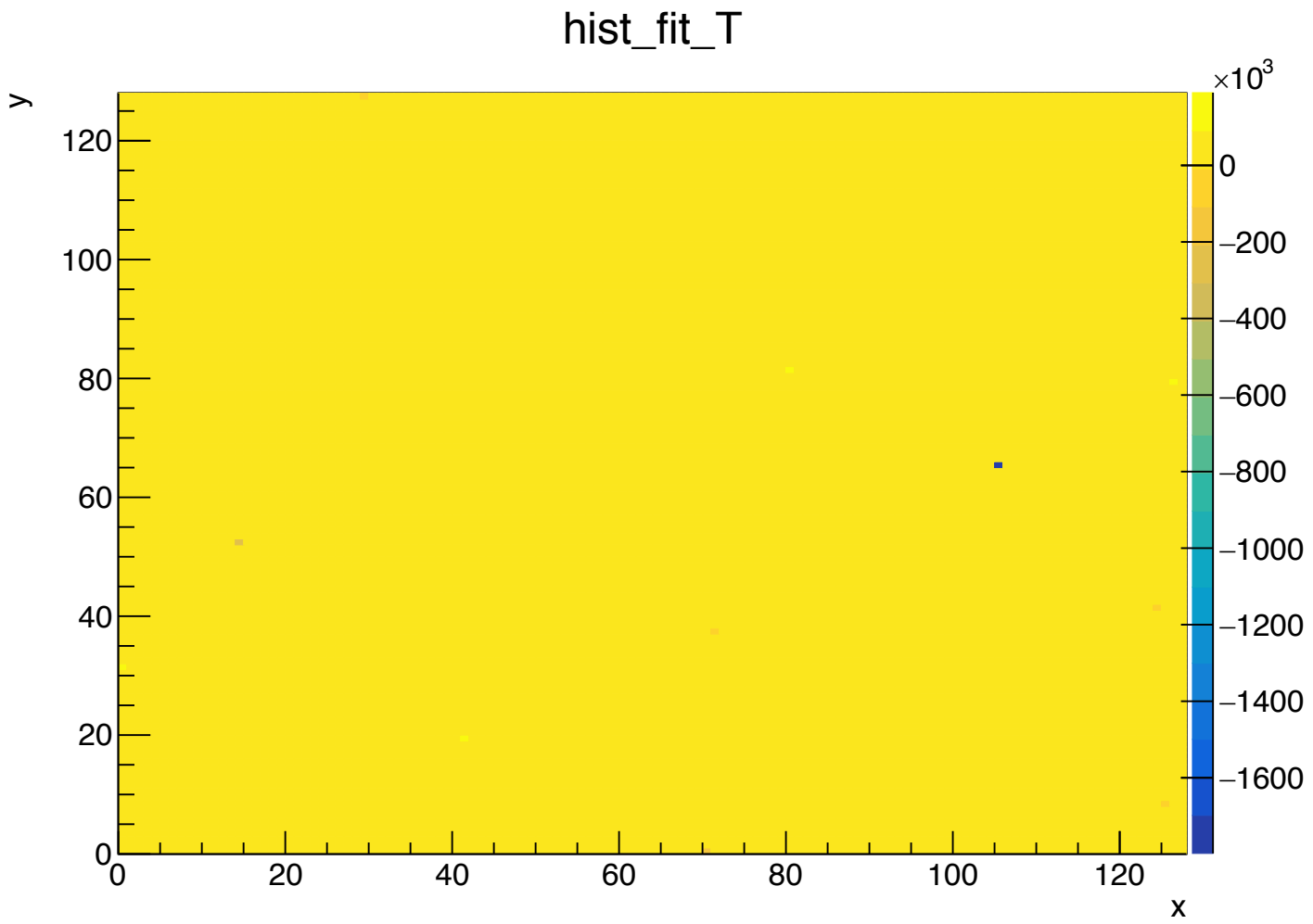
400
200
0


hist_fit_T
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x
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20
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60
80
100
120
×10^3
0
−200
−400
−600
−800
−1000
−1200
−1400
−1600